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Development of the Shaping-Lathe Headrig

Peter Koch

Southern Forest Experiment Station
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KOCH SHAPING-LATHE HEADRIG

The drawing on the opposite page depicts the commercial version of the Koch shaping-lathe headrig. This first production model, design of which is based on data derived from prototype trials described in the present paper, will be commercially making southern hardwood flakes and pallet cants by early spring of 1975. It carries a 54-inch-long, six-knife cutterhead with 12-inch cutting circle. The cutterhead is turned at 3,600 r/min by a 300-hp motor designed to momentarily carry a 200-percent overload without pullout from synchronous speed. The workpiece is driven from one end with a 5-hp, variable-speed motor that provides rotational speeds from 9 to 27 r/min. The headrig will accept bolts 3.5 to 12 inches in diameter and 40 to 53 inches in length. Feed rate is estimated at six bolts per minute. This initial production model was built under a Southern Forest Experiment Station contract with Stetson-Ross, Seattle, Wn.; funds were provided by the Branch of State and Private Forestry, USDA Forest Service.

Summary of Results From Prototype Trials

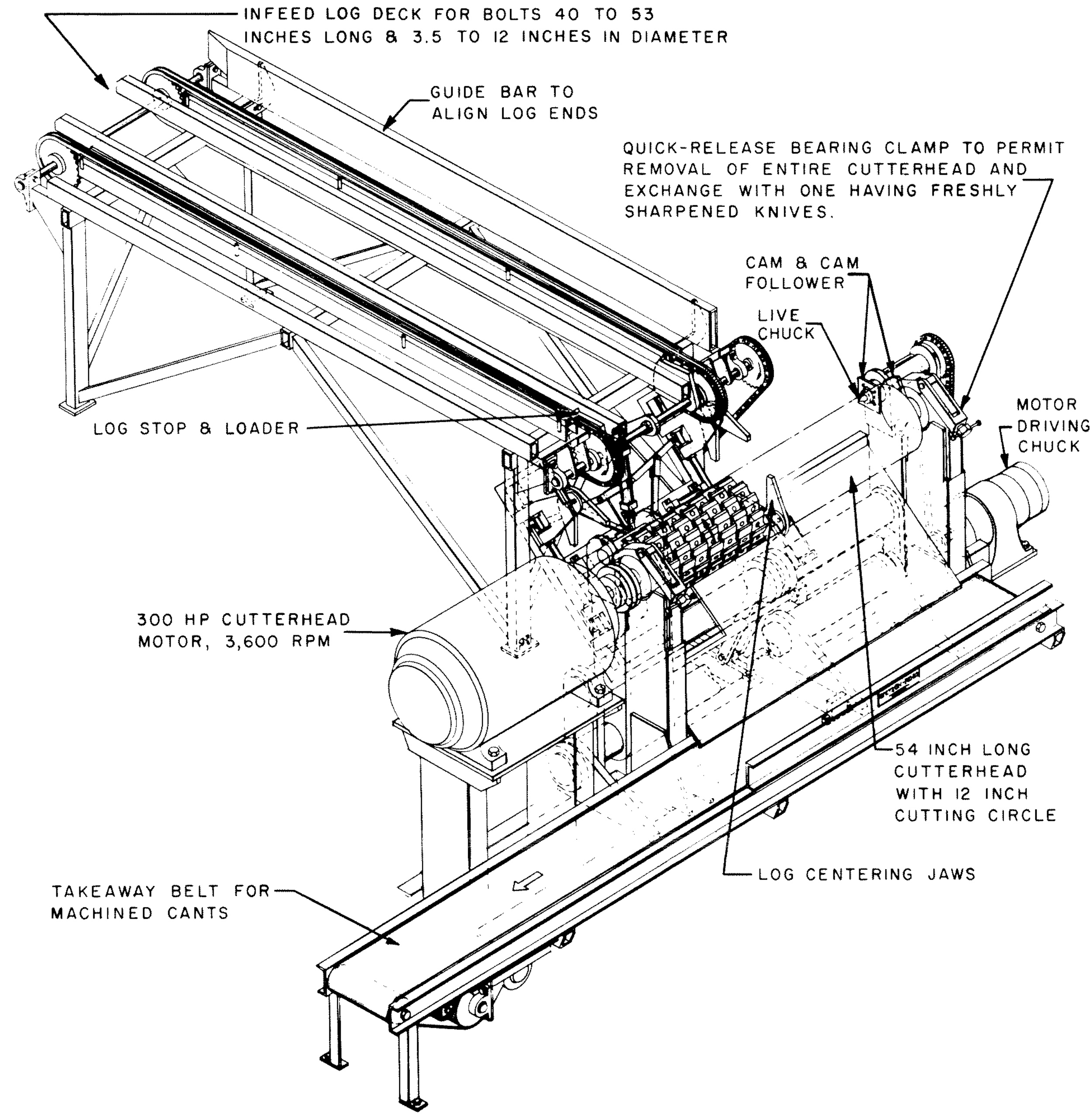
The headrig, cutting in the 0-90 mode, requires 3 to 6 seconds to machine end-chucked short hardwood or softwood logs. Output consists of cants having any desired polygonal shape, or round posts, plus flakes or pulp chips.

Removal of flakes leaves cants with excellent surface quality and dimensional accuracy. Up-milling is more practical than down-milling. Water-soaked wood cut at 160°F required 5.5 percent less net cutterhead power than green wood cut at 72°F. Net specific cutting energy showed positive linear correlation with wood specific gravity and negative correlation with flake thickness; for up-milling of hot and cold loblolly pine, sweetgum, hickory, and southern red oak, it averaged 9.92 hp minutes per cubic foot of wood removed as flakes 0.015, 0.025, and 0.035 inch thick.

To manufacture 0.015-inch-thick flakes with a six-knife head rotating at 3,600 r/min, average cutterhead demand will be about 267 hp when machining green, unheated hardwoods of 0.75 density, 12-inch diameter, and 53-inch length into 8- by 8-inch cants. Peak demand, assuming a maximum depth of cut of 3 inches, will be 510 hp.

If flakes 0.030 inch thick are cut with a three-knife head, average cutterhead demand will be about 206 hp when machining 8-inch squares from green, dense 12-inch bolts 53 inches long. Peak demand during 3-inch-deep cuts will be 356 hp.

One-and-one-half horsepower (net delivered to the workpiece spindle at all spindle speeds), should be sufficient to turn against peak forces exerted by the cutterhead. Bolt deflections in bending and torsion should not be severe when cants having diameters above 6 inches are being machined. If bolts are highly eccentric (for example, if 3-inch-deep cuts are needed to make 4-inch-round posts), however, bending deflections may be as much as 1/16- to 1/8-inch, and torsional deflection may be 2 degrees.



Sketch of commercial version of the shaping-lathe headrig, including log deck, centering device, charger, and takeaway conveyor for machined cants. Flakes are blown from the cutterhead hood (removed for purposes of this illustration) for conveying to flakeboard plant. Design feed rate is six logs per minute. Smoothly machined cants will have the shape and dimensions of replaceable cams mounted on the workpiece spindle. (Drawing from Stetson-Ross, Seattle.)

Koch, Peter

1974. Development of the shaping-lathe headrig. South. For. Exp. Stn., New Orleans, La. 20 p. (USDA For. Serv. Res. Pap. SO-98)

A prototype yielded data for designing a commercial headrig capable of machining end-chucked hardwood or softwood bolts into cants for pallet boards or posts of any desired round or polygonal shape. Wood removed is in the form of flakes or pulp chips. Net specific cutting energy showed positive linear correlation with wood specific gravity and negative correlation with flake thickness. A 54-inch cutterhead carrying six knives and rotating at 3,600 r/min will average 270 horsepower when machining green, unheated hardwoods of 0.75 density, 12-inch diameter, and 53-inch length into cants 8 inches square and flakes 0.015 inch thick; peak power requirements for cuts 3 inches deep will be about 510 horsepower.

Additional keywords: Southern pine, *Pinus taeda, Liquidambar styraciflua, Quercus falcata, Carya* spp., power requirements, specific cutting energy, chipping headrigs and edgers, pallets, short logs, bolts, machining, milling, cants, lumber, flakers, flaking, chippers, chipping, pulp chips, surface quality, rake angle, clearance angle, sharpness angle, chip quality, flakeboard, particleboard.

DEVELOPMENT OF THE SHAPING–LATHE HEADRIG

Peter Koch

The decade 1964-1974 has seen widespread application of chipping headrigs cutting in the 90-0 and 90-90 modes (Koch 1964, 1967a, 1968, 1972, p. 832-846). These headrigs have been applied primarily in conversion of straight softwood logs 8 feet or more in length. Products are dimension lumber and pulp chips. The machines are not well suited for logs with butt swell, crook, or sweep. Cants characteristically display some torn grain, particularly around knots.

A prototype headrig cutting in the 0-90 mode (fig. 1) was first demonstrated more than 10 years ago (Koch 1964, 1967b), and now nears commercial application. Operating on the principle of a shaping lathe, it is particularly adapted to short logs of irregular contour, since it relies for workpiece position on end chucks rather than on through-feed chains or rolls. Smoothness of the machined surfaces approaches that of millwork. In contrast with other headrigs, this version can readily produce rounds, hexagons, octagons, or trapezoids as well as square or rectangular cants. Thus it lends itself to the manufacture of pallet parts and other industrial lumber, together with posts and rails for fencing. Moreover, its residue is veneer-like particles well adapted for use in structural flakeboard. Such flakes are commonly 2 to 3 inches long, 0.015 to 0.045 inch thick, and perhaps 3/8-inch wide.

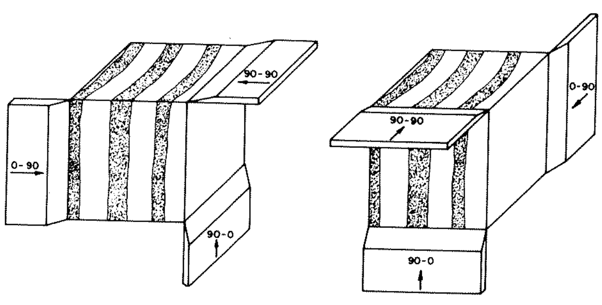


Figure 1.—*Designation of the three major machining directions. The first number is the angle the cutting edge makes with the grain; the second is the angle between cutter movement and grain.*

Three current trends in forest resources and markets favor the development and application of a shaping-lathe headrig. First, supplies of high-quality logs have diminished, while small hardwoods of low quality remain relatively abundant throughout much of Eastern United States. Second, demand for pallet lumber has risen rapidly in recent years, and the headrig is particularly well suited to convert small hardwoods into pallet cants. Finally, structural exterior flakeboard is being test-marketed and appears likely to take over part of the market for sheathing grades of plywood. The product is currently manufactured from softwoods and aspen (*Populus* sp.), but research indicates that it can be made from mixed eastern hardwoods.

This paper describes a second prototype of sufficient size to provide information for designing and building a commercial model suited to hardwood logs 40 to 53 inches long and 3.5 to 12 inches in diameter.

The new prototype, built under contract with Stetson-Ross of Seattle, Washington, is capable of chucking a 12-inch-diameter bolt 6.5 inches long (fig. 2). Bolts to be machined are clamped in the chucks of the workpiece spindle, which turns at about 15 r/min. Attached to the spindle is a replaceable cam having the shape and dimensions of the desired cant. The cam rotates and moves with the workpiece until it strikes a follower aligned with the cutterhead. As the workpiece makes a single revolution, the center distance between cutterhead and workpiece changes in response to the cam, and the workpiece (log) is machined to the shape and dimensions of the cam. Since the log makes only a single revolution while being sized, machining time is brief—approximately 4 seconds.

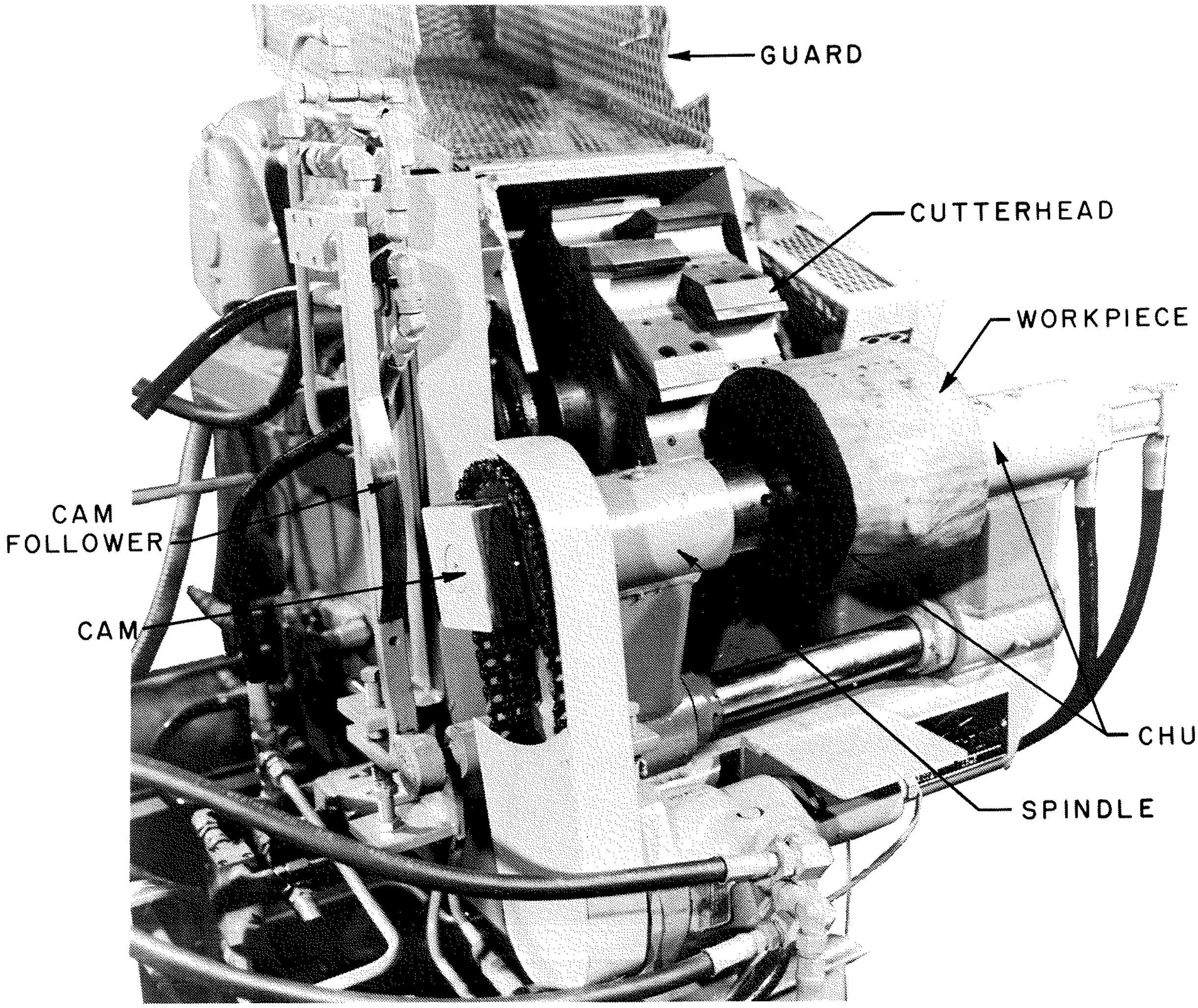


Figure 2.—*Second prototype of Koch shaping-lathe headrig, with 10-knife flaking cutter in place. Cam is 4 inches square. The bolt, when machined, will also measure 4 inches square.*

The cutterhead is 18 inches in diameter and is turned at 1,800 r/min by a 30-hp motor. Configuration of knives is shown in figure 3. To mimimize power requirement and enhance flake quality, rake angle is large—43°. Clearance angle, at 5°, is considered the minimum necessary to avoid undue interference with the workpiece. The resulting sharpness angle of 42° yields a cutting edge moderately resistant to nicking.

The cutterhead is in two segments, each 3-1/2 inches long and slotted for 10 knives; if desired, half the knives can be removed, so that only five are cutting. The two segments are indexed 18° from each other, to cause flake severance at their junction.

PRELIMINARY EXPERIMENT

A test program was executed in the Seatt factory of Stetson-Ross to evaluate cutterhea action when reducing 6-inch rounds to 4-in squares. Factors were:

- Species
  - Sweetgum (*Liquidambar styraciflua* L.)
  - Southern red oak (*Quercus falcata* var. *fa cata*)
  - Hickory (*Carya* sp.)
- Wood temperature
  - Stored in water at room temperature
  - Heated in water at 180° F
- Cutting direction
  - Up-milling
  - Down-milling

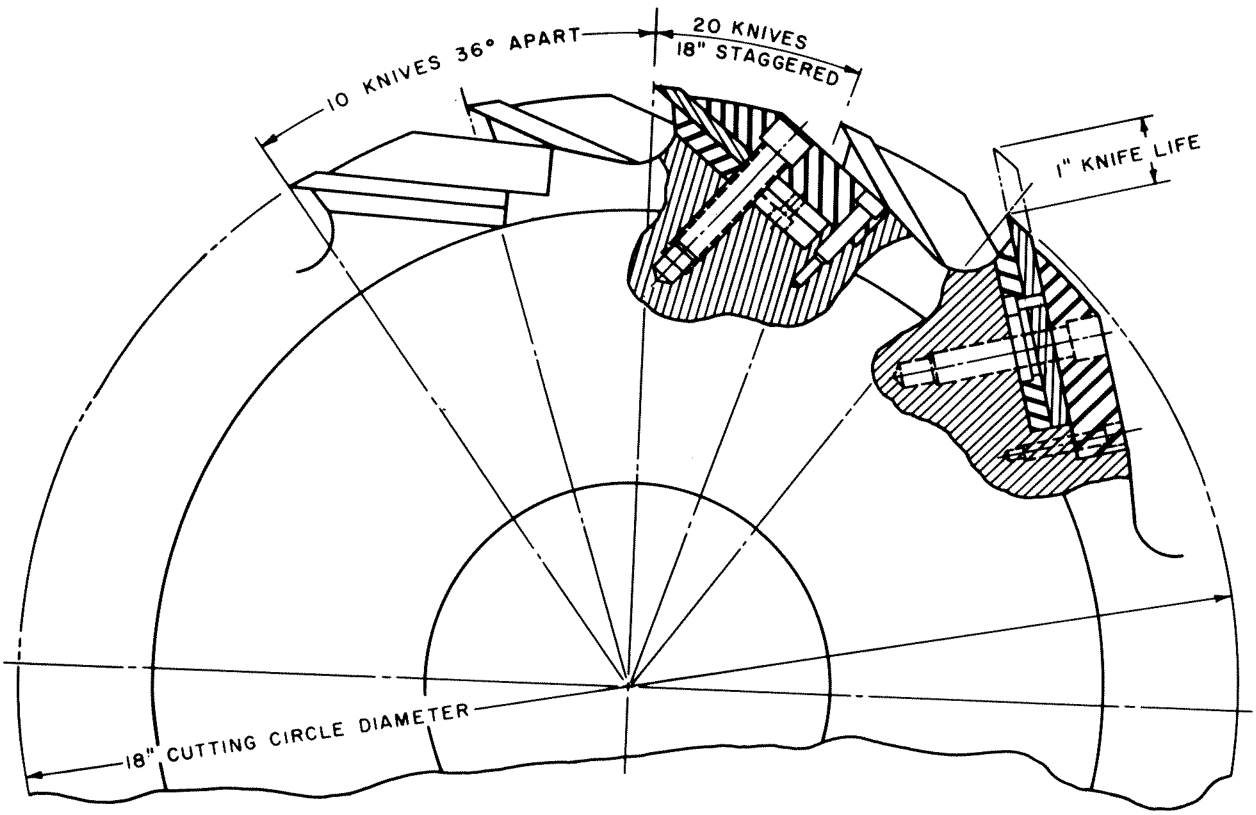


Figure 3.—*Cross-section through flaking head, showing system of clamping 10 knives in each of two disks with rake angle of 43° and clearance angle of 5°. Knives were smooth on both sides, 3-1/2 inches long, and 1/4-inch thick.*

Product

- Flakes 0.015 inch thick by 3 inches long
- Pulp chips 0.15 inch thick by 5/8-inch long
- Matchsticks about 0.05 inch thick and 3 inches long (cut only from oak at room temperature).

The flakes and matchsticks were cut with the 10-knife head (fig. 2) from bolts 6 inches in length. For the pulp chips, special one-knife cutterheads of the type shown in figure 4 were stacked with segments staggered to form an assembly 6 inches long. Cutters were designed to make chips 5/8-inch along the grain. Rotational speed of the workpiece was set to give average chip thickness desired.

In preliminary runs, it was determined that the lathe would faithfully reproduce the dimensions and shape of a wide variety of cams (fig. 5). The flaking head yielded very smooth surfaces on all three species tested; figure 6 shows results on sweetgum and red oak. Surfaces made by the pulp chip cutterhead were comparatively rough (fig. 7).

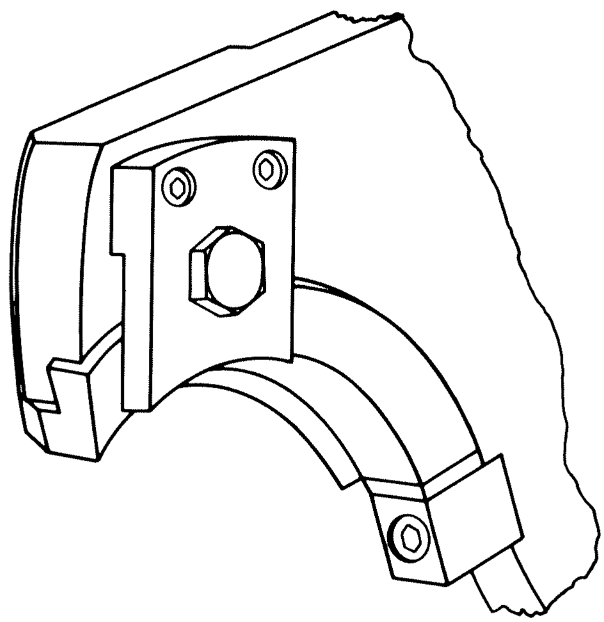


Figure 4.—*Detail of the pulp chip knife shown in figure 11. Cutting-circle diameter was 18 inches.*

Figure 5.—*Typical cams*
Koch lathe. T
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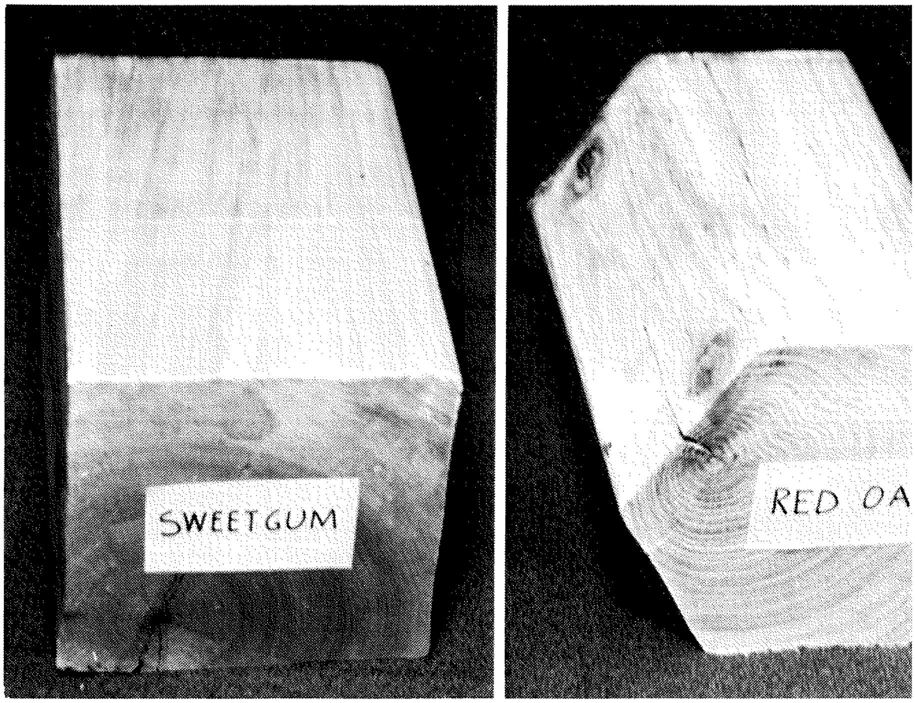

Figure 6.—*Cants smoothly machined by removal of flakes 0.015 inch thick.*

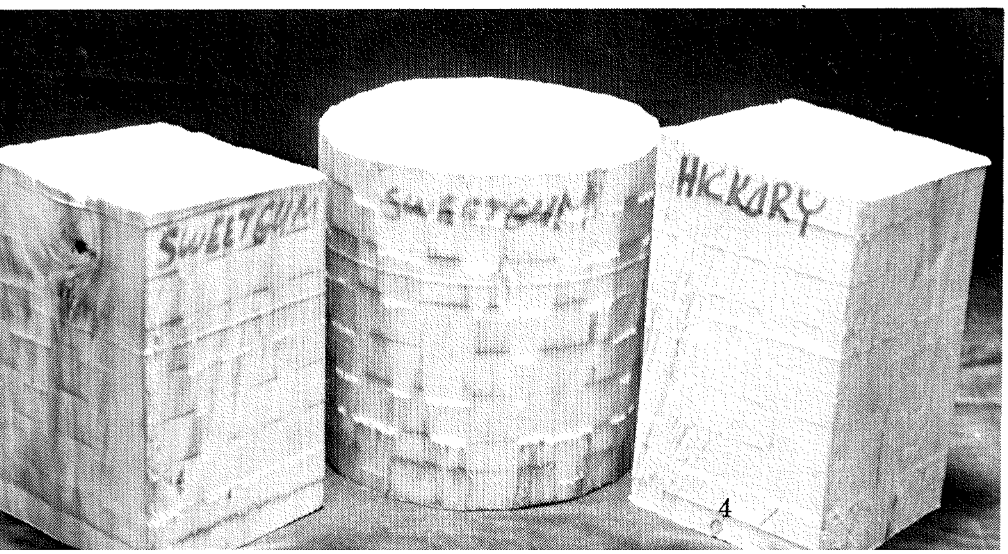

Figure 7.—*Cants from wh*
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surfaces.

Flake appearance differed greatly with species. In general, sweetgum (and southern pine) flakes were wide and flat; hickory flakes were wide but tended to roll up into cigarette shape. Oak flakes tended to be splinter-like. Flakes cut hot averaged wider than those cut cold, since they splintered less. Up-milled flakes were less splinter-like than down-milled flakes (figs. 8 and 9).

To make matchstick-like particles for the structural matrix in foamed urethane products[1], oak was revolved at a speed calculated to yield

[1] Marra, A. A. **Analysis of the utility of southern hardwoods as a furnish for low-density composite products.** USDA For. Serv. South. For. Exp. Stn., Alexandria, La., Final Report FS-SO-3201-2.42, March 1974.

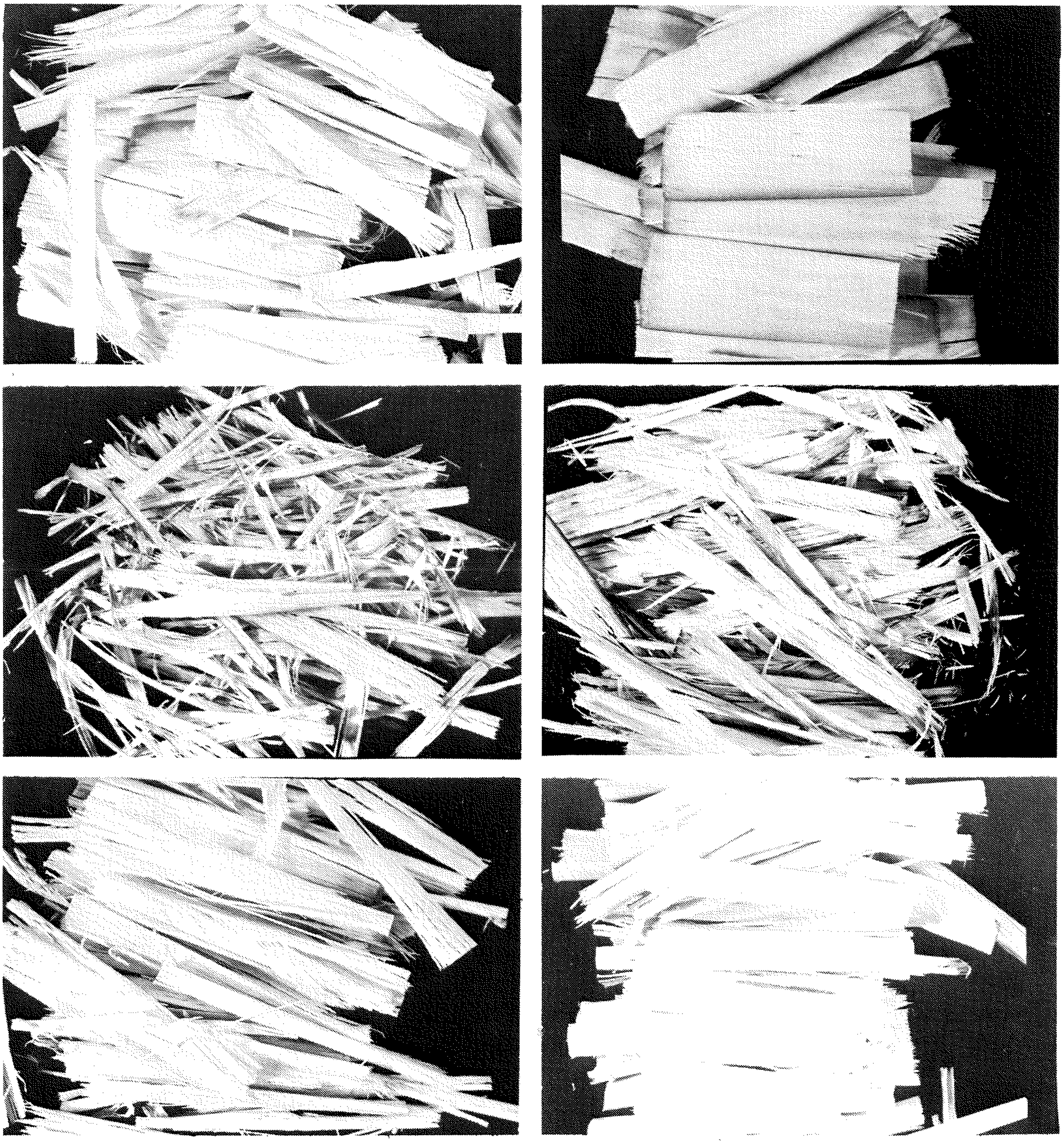

Figure 8.—*Up-milled flakes 0.015 inch thick and 3 inches long cut from sweetgum (top), southern red oak (center), and hickory (bottom) soaked in water at 72°F (left) and 160°F (right).*

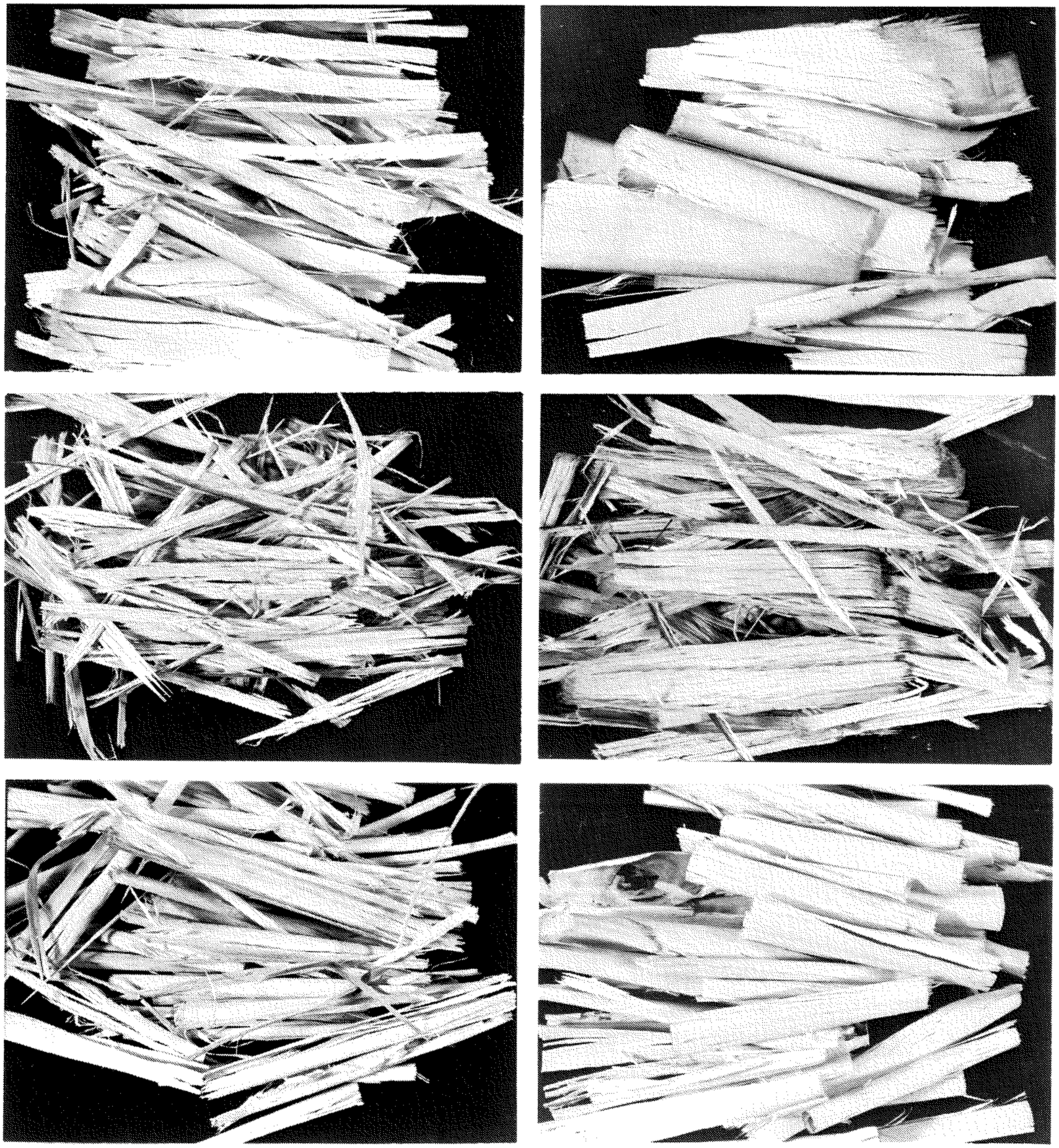

Figure 9.—*Down-milled flakes 0.015 inch thick and 3 inches long cut from sweetgum (top), southern red oak (center), and hickory (bottom) soaked in water at 72°F (left) and 160°F (right).*

splinters 0.05 inch thick plus a hexagon measuring 4 inches across the flats. Cant surface remained good with no tearout around knots. The matchsticks tended not to be severed into 3-inch-long particles; many were 6 inches long, i.e., the length of the bolt (fig. 10).

The stacked disks, which had gullets somewhat obstructed, yielded pulp chips that contained high proportions of pin chips, particularly in oak. In an effort to improve chip flow, a new single-knife disk was constructed in which the gullet was smooth and capacious. To eliminate the

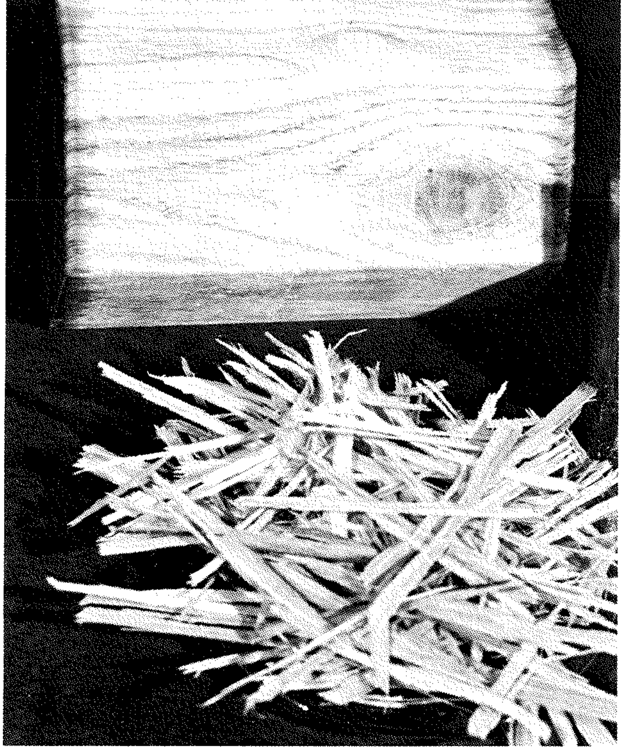

Figure 10.—*Matchsticks about 0.05 inch thick up-milled (top) from southern red oak at 72° F to leave a hexagonal cant.*

complication of severing the fibers of each chip to length, the workpiece was reduced to 5/8-inch along the grain (fig. 11). Resulting chips are depicted in figures 12 and 13. Motion pictures taken at 6,000 frames per second indicated that chambering action was unimpeded. It is likely, therefore, that refinement of head design will

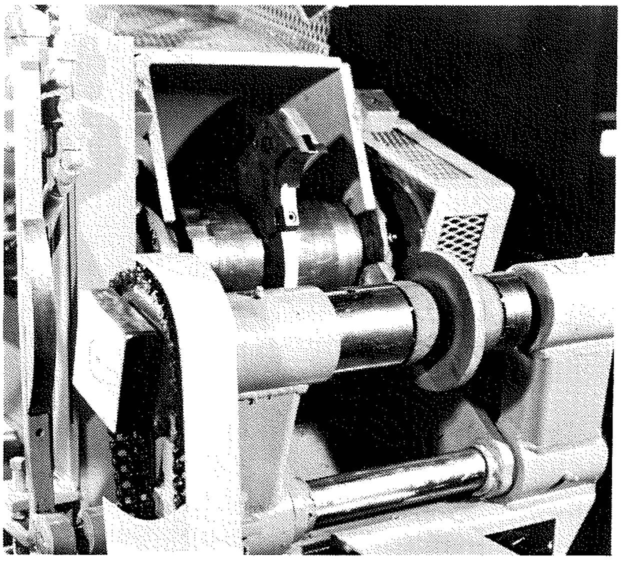

Figure 11.—*One-knife head for making pulp chips 5/8-inch long.*

not improve chip quality greatly. While chips of the type illustrated are less than desirable for chemical pulp, they should make excellent furnish for mechanical pulp produced in disk refiners.

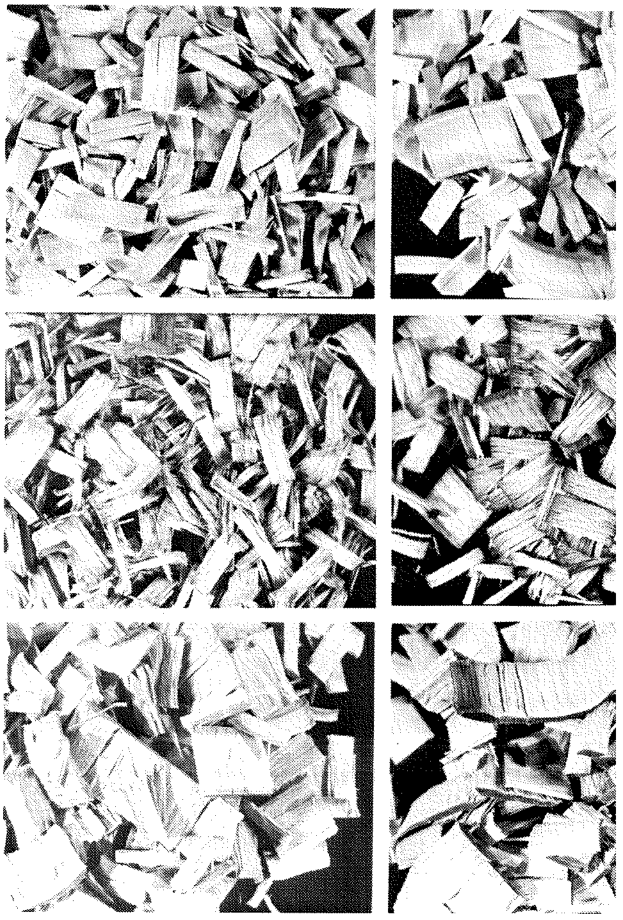

Figure 12.—*Up-milled pulp chips 0.15 inch thick cut from sweetgum (top), southern red oak (center), and hickory (bottom) soaked in water at 72°F (left) and 160°F (right). Bruised fiber ends were not caused by chipping knife but resulted from prior machining of bolt to establish 5/8-inch chip length.*

PROCEDURE IN DETERMINING POWER REQUIREMENT

At the conclusion of the Seattle trials, the machine was displayed under power in Atlanta, Georgia, where it stimulated great interest at the June 1973 machinery show of the Southern Forest Products Association (Mason 1973). From Atlanta, it was shipped to the Southern Forest Experiment Station's laboratory at Pineville, Louisiana.

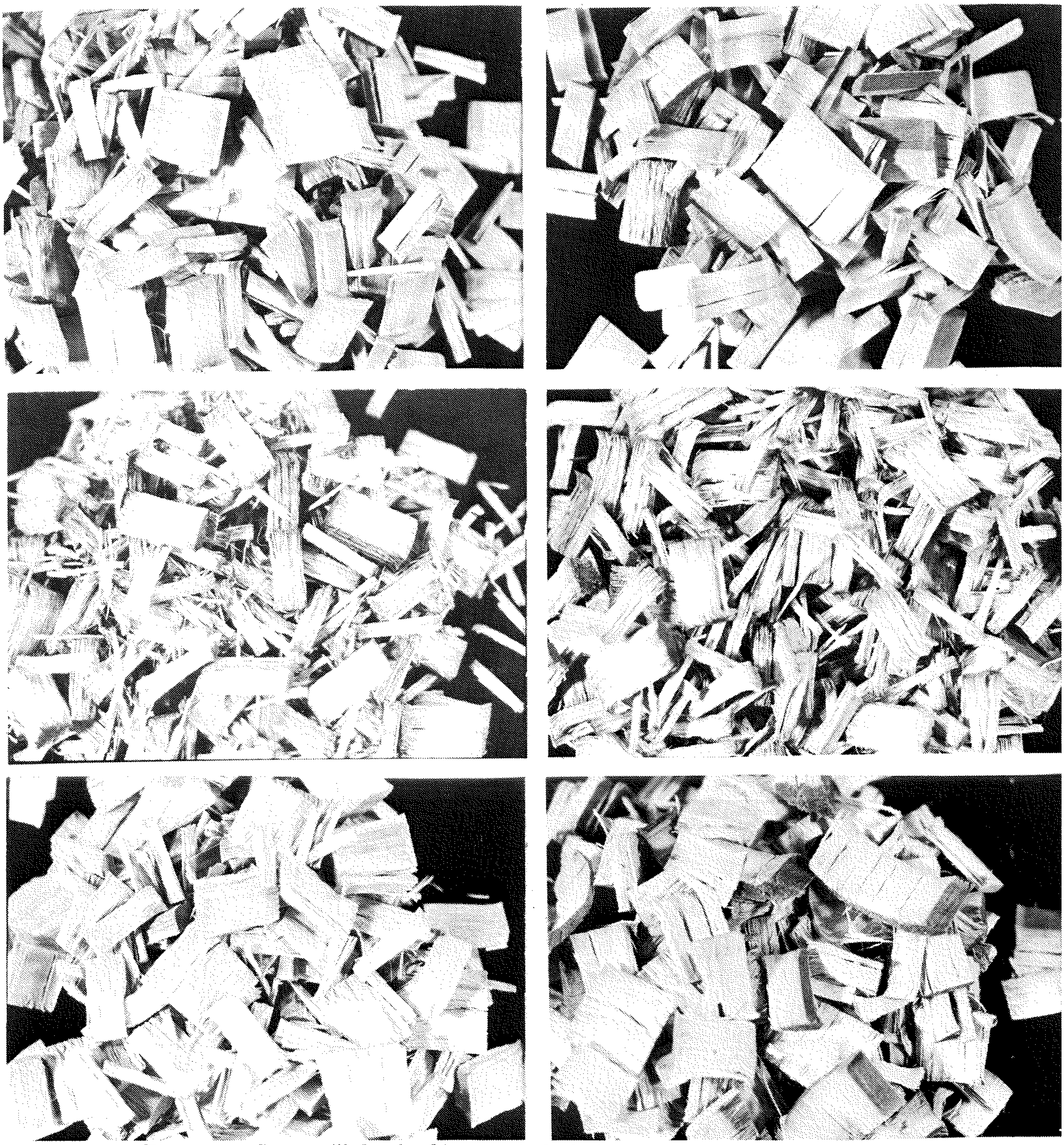

Figure 13.—*Down-milled pulp chips 0.15 inch thick cut from sweetgum (top), southern red oak (center), and hickory (bottom) soaked in water at 72°F (left) and 160°F (right). Bruised fiber ends were not caused by chipping knife, but resulted from prior machining of bolt to establish 5/8-inch chip length.*

The purpose of the Louisiana phase of the study was determination of specific cutting energy and maximum cutterhead power demand when making flakes from several species under a variety of cutting conditions. The flaking head was the same one used in Seattle (figs. 2 and 3).

It had been determined that power to turn the 6-inch-long workpieces past the flaking head was very small; the net was about 0.05 hp. Further observations of workpiece spindle power were not made.

At the outset, it was observed that flakes cut in the down-milling mode from large-diameter bolts tended to be more splinter-like than flakes cut by up-milling. Such splinters are undesirable because the fines they contain make glues less effective in bonding structural boards. On the larger bolts, moreover, the clearance side of knives (backs) tended to rub on the advancing bolt; this interference made control of workpiece r/min (and hence flake thickness) difficult. A further argument for up-milling is that the knife enters the cut at a cleanly machined surface and leaves at the outer surface of the bolt. The opposite is true of down-milling, so that dirt on the bolt is more likely to cause dulling. For these reasons, the Louisiana phase was confined to up-milling, with only sufficient data on down-milling to get an estimate of specific cutting energy.

Factors in the Louisiana phase (up-milling) were:

- Species
  - Sweetgum
  - Southern red oak
  - Hickory
  - Loblolly pine (*Pinus taeda* L.)
- Temperature of green bolt at time flakes were cut
  - Low (72° F)
  - High (160° F)
- Flake thickness on average, inch
  - 0.015
  - 0.025
  - 0.035
- Outside diameter of bolt, inches
  - 6
  - 7
  - 8
- Replications of bolts: six

A total of 432 bolts were therefore turned, i.e., (four species) (two temperatures) (three flake thicknesses) (three diameters) (six replications). All bolts were machined to a cylindrical core 4 inches in diameter.

Prior to flaking, all bolts were accurately machined to the specified diameter and sawed to 6.45-inch length. At the time each bolt was prepared, an adjacent 1-inch-thick cross-sectional slice was removed from the tree stem and left with the bolt. When the bolt was flaked, moisture content and specific gravity were determined from the wood outside the 4-inch central core of the mated slice.

Guidelines for running the experiment were:

- The replications were blocks in time.
- Room-temperature wood was cut in the mornings; bolts to be flaked hot were heated 4 hours in 160° F water during the morning and cut in the afternoon. While awaiting evaluation, bolts (with accompanying slices) were stored outside under water.
- In each day of operation, flakes of a single thickness were cut.
- Flakes 0.015 inch thick were cut with 10 knives in the cutterhead; for 0.025- and 0.035-inch flakes, alternate knives were removed to leave only five cutting. Workpiece r/min are shown in table 1; they ranged from 11.8 to 20.2 and were computed to yield the desired flake thickness at the bolt radius midway between 2 inches and the outer radius. It would have been desirable to do all cutting with 10 knives, but the machine design is such that workpiece speeds of 10 to 20 r/min are most practical; a workpiece speed of near 40 r/min would have been required to cut 0.035-inch flakes with a 10-knife head. The cutterhead (18-inch cutting circle diameter) turned at 1,800 r/min under no load, and had negligible drop in r/min under the average load imposed by the tests.

Table 1.—*Schedule of actual workpiece rotational speeds with target and achieved average flake thicknesses*[1]

Target flake thickness[2]	Achieved flake thickness[2]	Bolt outside diameter		
		6	7	8
——— *Inch* ———		——— *R/min* ———		
[3]0.015	0.0149	17.0	15.6	14.3
[4] .025	.0248	14.3	12.9	11.8
[4] .035	.0350	20.2	18.0	16.6

[1] The cutterhead rotated at 1,800 r/min.

[2] Figured at average depth of cut from outside diameter to the 4-inch cylindrical core.

[3] The cutterhead carried 10 knives.

[4] The cutterhead carried 5 knives.

Data recorded for each bolt (in addition to moisture content and specific gravity of the outer portion of the mated slice) were as follows: bolt length, workpiece r/min, watt-seconds consumed by the 30-horsepower cutterhead motor, and maximum watts demanded by the cutterhead motor. The workpiece r/min and instantaneous watt requirement of the cutterhead were recorded on strip charts moving at 25 mm per second to permit later computation of average flake thickness, average cutterhead power demand, and watt-seconds of energy to make each entire cut. From these data, plus a knowledge of cutterhead power demand when idling, it was possible to compute the energy input per cubic foot of wood removed.

Finally, an analysis was made of brake horsepower output related to watts input to the cutterhead motor (fig. 14). These data permitted computation of net specific cutting energy expressed as net horsepower minutes per cubic foot of wood removed. This computation was the primary objective of the experiment, as the information was needed to size the cutterhead motor on the commercial Koch lathe being designed at the time. The cutterhead on the commercial model is 54 inches long. For convenience in analysis and application of average and maximum net horsepower information, the data are presented for bolts 50 inches long.

At the beginning of the experiment, knives were freshly sharpened. By the time all 432 bolts had been run (main experiment) some knives were beginning to develop small nicks and slight dulling.

The central residual pieces were saved from the last two replications, and their surface quality was visually evaluated.

Cutting began in September 1973, proceeded at the rate of 24 bolts per day, and was completed October 19, 1973.

Limited down-milling data were taken a few days later on green sweetgum bolts only, cut at 72° F to 4-inch diameter, in a factorial arrangement:

Cutting direction
- Up-milling
- Down-milling

Flake thickness, inch
- 0.015
- .025
- .035

Bolt diameter, inches
- 6
- 7
- 8

Replications: 3.

Thus, 27 bolts were cut in the downmilling dire tion for comparison with 27 bolts of sweetgu upmilled at 72° F (selected from replications the main experiment to closely match the sp cific gravity of bolts downmilled) for a total 54 bolts.

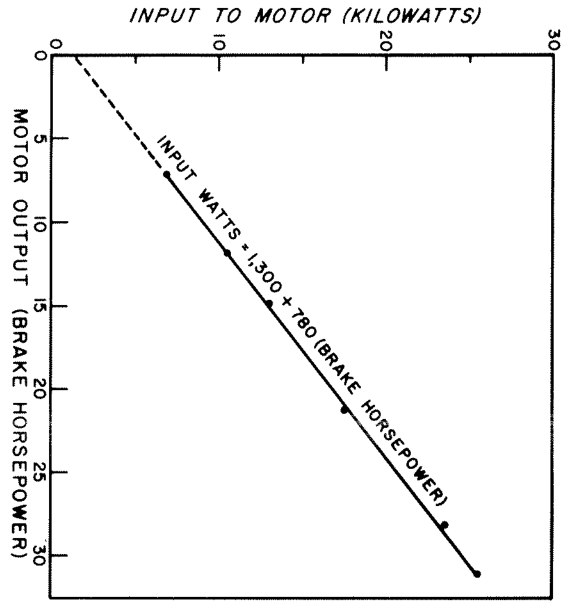

Figure 14.—*Brake horsepower output related to watts input to cutterhead motor, as determin by prony brake test. Motor speed und load did not fall below 1,760 r/min. Mot nameplate data were as follows:*

H.P. 30; r/min 1,760
Frame 286T; Type R; 40° C
460 volts; 36.5 A
Design B; Code G; SF 1.15
ID R-9442-00-004-J (U.S. Elec. Mot

DOWN-MILLING VS. UP-MILLING

The 54 sweetgum bolts in the comparison down-milling and up-milling averaged 0.487 specific gravity. There was no significant di ference in specific gravity between the bolts u milled (0.484) and those down-milled (0.491 Moisture content averaged 139.2 percent for bolts.

On average, bolts down-milled required 5.2 percent more specific cutting energy than those up-milled:

Flake thickness	Up-milling	Down-milling
Inch	*Horsepower minutes per cubic foot removed*	
0.015	11.29	11.06
.025	8.90	9.82
.035	7.98	8.78
Average	9.39	9.88

The 27 down-milled bolts were cut after the 432 bolts of the main experiment had been up-milled. The difference tabulated above may therefore be largely attributable to dullness of knives.

Machined surfaces of down-milled bolts were smooth and indistinguishable in quality from those up-milled.

RESULTS AND DISCUSSION: UP-MILLING

Surface Quality

Flake thickness, bolt diameter, and cutting temperature did not noticeably affect quality of machined surfaces. Nor did surface quality visibly deteriorate with progression of replication, except that traces from minor knife nicks became visible as replications proceeded.

Machined cylinders of all four species had surfaces that approached millwork quality. The distinguishing marks of wood machined on the shaping-lathe headrig are faint circumferential traces across the grain at regular intervals. These traces define the length of cutterhead knife segments, which in turn determine flake length.

Dulling of Knives

Some dulling of the knives occurred as the 432 bolts in the main experiment were up-milled. Because the six replications were sequentially blocked in time, the increase observed in specific cutting energy from replication 1 to 6 (10.5 percent) and the increase of maximum net horsepower per knife per 50 inches of bolt length (8.5 percent) gave some indication of the progress of dulling. In the following tabulation, data from all factors are pooled:

Replication	Net specific cutting energy	Maximum net cutting power per 50 inches of bolt length per knife
	Hp minutes/ft³	*Horsepower*
1	9.40	18.05
2	9.34	17.60
3	9.95	18.15
4	10.26	19.18
5	10.20	19.24
6	10.39	19.58

While machining the 432 bolts, the cutterhead was actually cutting wood for about 51 minutes. At a charging rate of six bolts per minute for the commercial machine, about 1,200 bolts may be machined during a morning's work, with actual machining time of 150 minutes or less. Extension of the data in the foregoing tabulation to 1,200 bolts indicates a likely increase in net cutterhead horsepower of near 20 percent from morning installation of freshly sharpened knives to mid-shift replacement.

Specific Gravity

Specific gravity of the flaked portion of bolts varied significantly (0.05 level) according to species and bolt diameter in the following interaction:

Species	Bolt diameter, inches 6	7	8	Average
Sweetgum	0.48	0.46	0.47	0.47
Loblolly pine	.46	.50	.52	.49
Southern red oak	.61	.60	.58	.58
Hickory	.70	.69	.68	.69

Specific gravity of hickory and red oak varied inversely with bolt diameter, that of loblolly was positively correlated with bolt diameter. No diameter-related trend was evident for sweetgum. Average specific gravity of all bolts up-milled was 0.56.

Bolts assigned to the three flake-thickness and two soaking treatments did not vary in specific gravity.

Moisture Content

With data from all bolts pooled, moisture content of portions flaked was 110.6 percent. Bolts heated in hot water before machining had 4.3

percentage points less moisture content (108.4 percent) than those stored in cold water (112.7 percent); the difference was significant at the 0.05 level.

Partly in consequence of the specific gravity relationships just discussed, hickory and red oak had lower moisture contents than loblolly pine and sweetgum:

Species	Bolt diameter, inches 6	7	8	Average
	— *Percent of dry weight* —			
Hickory	66.2	68.8	68.9	68.0
Southern red oak	91.2	95.3	100.8	95.8
Loblolly pine	145.1	127.1	123.3	131.8
Sweetgum	145.5	149.1	145.3	146.7

In hickory and oak the highest moisture contents occurred in the 8-inch bolts; in loblolly pine, however, 6-inch bolts had the highest.

Idle Horsepower

The relationship between input wattage to the cutterhead motor and output mechanical horsepower was proven linear by a prony brake test (fig. 14).

When the 7-inch-long, 18-inch-diameter cutterhead was vee-belted to this motor, 2.9 horsepower were required to rotate the head at 1,800 r/min. This idling horsepower was the same whether the cutterhead was fitted with 10 knives or 5.

Horsepower to idle is primarily comprised bearing friction and windage. The first of the components should be proportional to the weig of the cutterhead (and thereby the length); t second component should be directly related cutterhead length.

From the test data, it can be predicted th idle power required to drive a 54-inch-long cu terhead will be about 22 horsepower, i.e., (54/ (2.9). This value is for a cutterhead speed 1,800 r/min with cutting circle 18 inches diameter. It is likely that a head 12 inches diameter rotating at 3,600 r/min would n differ substantially in idling demand.

Net Specific Cutting Energy

The statistic of foremost importance in dete mining average power requirements of a wo machining operation is net specific cutting e ergy, that is, the energy (over and above idli energy) required to remove a unit volume wood in a unit time.

For the entire up-milling experiment, specif cutting energy averaged 9.92 horsepower mi utes per cubic foot. Uncomplicated by intera tions with other factors, wood soaked in 160° water required 5.5 percent less specific cutti energy than wood held in water at 72° F (9. vs. 10.21 horsepower minutes per cubic foot).

Specific gravity of wood was positively corr lated with specific cutting energy (fig. 15 flake thickness had a negative correlation (fi

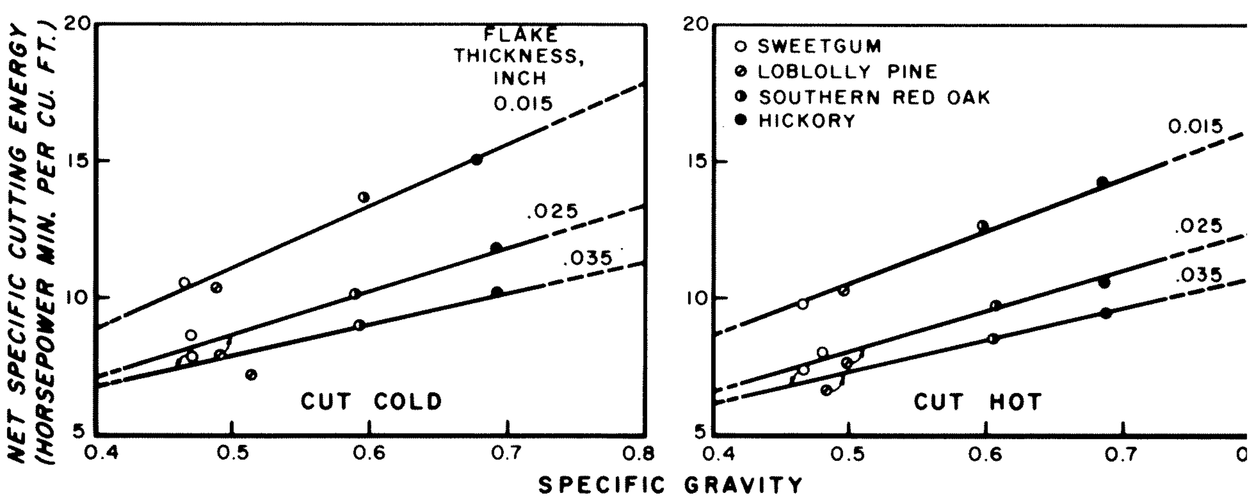

Figure 15.—*Regression of specific cutting energy on wood specific gravity (basis of ovendry weight and green volume) for wood cut at 72°F (left) and 160°F (right). Plotted points are averages for the species named.*

16 and table 2). Thus, hickory flakes cut 0.015-inch thick from 72-degree wood averaged 15.04 horsepower minutes per cubic foot, whereas loblolly pine flakes cut 0.035-inch thick from 160-degree wood averaged only 6.52 (table 2). No bolts exceeded a specific gravity of 0.73; the minimum was 0.42.

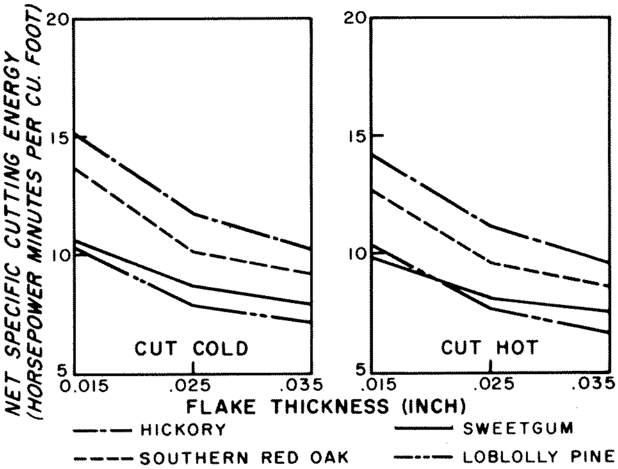

Figure 16.—*Net specific cutting energy as related to average flake thickness, species, and wood temperature. Data from 18 bolts were averaged to locate each of the 24 points plotted.*

Table 2.—*Specific cutting energy related to flake thickness, wood temperature, and species*

Temperature and species	Flake thickness, inch			
	0.015	0.025	0.035	Average
	Horsepower min/ft³			
Cut cold				
Loblolly pine	10.32	7.89	7.21	8.47
Sweetgum	10.54	8.68	7.90	9.04
Southern red oak	13.67	10.15	9.15	10.99
Hickory	15.04	11.76	10.16	12.32
Average	12.39	9.62	8.60	
Cut hot				
Loblolly pine	10.32	7.68	6.52	8.18
Sweetgum	9.82	8.04	7.50	8.45
Southern red oak	12.69	9.58	8.55	10.27
Hickory	14.25	11.15	9.57	11.66
Average	11.77	9.12	8.04	

The data indicate that at all flake thicknesses and both temperatures loblolly pine had lower specific cutting energy than its specific gravity would indicate (fig. 15).

The regression equations graphed in figure 15, with squared correlation coefficients and square roots of error mean squares (values of S_e are in horsepower minutes per cubic foot), are as follows:

Wood cut at 72° F

0.015-inch flakes ($R^2 = 0.72$; $S_e = 1.29$)

$$\hat{Y} = -0.1937 + 22.6177\,X$$

0.025-inch flakes ($R^2 = 0.68$; $S_e = 1.01$)

$$\hat{Y} = 0.9244 + 15.5586\,X$$

0.035-inch flakes ($R^2 = 0.61$; $S_e = 0.84$)

$$\hat{Y} = 2.2545 + 11.2798\,X$$

Wood cut at 160° F

0.015-inch flakes ($R^2 = 0.66$; $S_e = 1.28$)

$$\hat{Y} = 0.9034 + 19.4060$$

0.025-inch flakes ($R^2 = 0.67$; $S_e = 0.95$)

$$\hat{Y} = 0.5955 + 15.0228\,X$$

0.035-inch flakes ($R^2 = 0.72$; $S_e = 0.70$)

$$\hat{Y} = 1.6473 + 11.4714\,X$$

From figure 15 it is evident that specific cutting energy is greatest when dense wood is cut cold into thin flakes. If it is assumed that 0.8 is near the upper limit of density for mixed eastern hardwoods, then (by the first equation listed above) the specific cutting energy when making 0.015-inch flakes will be maximum at 17.9 horsepower minutes per cubic foot of wood removed.

Because of contrasting species patterns of variation in bolt specific gravity with bolt diameter, net specific cutting energy also varied significantly with bolt diameter. With all flake thicknesses and both temperatures pooled, averages were as follows:

Species	Bolt diameter, inches 6	7	8	Average
	Hp min/ft³			
Loblolly pine	8.46	8.06	8.46	8.33
Sweetgum	8.95	8.65	8.63	8.75
Southern red oak	11.34	10.52	10.03	10.63
Hickory	12.56	11.83	11.57	11.99
Average	10.33	9.77	9.67	

Loblolly and sweetgum diameters showed little relationship with specific cutting energy. For southern red oak and sweetgum, however, specific cutting energy decreased as bolt diameter increased. While the differences related to bolt diameter are statistically significant, they are probably not large enough to cause problems for users of the commercial machine.

Average Net Cutterhead Horsepower Per 50 Inches of Bolt Length

Power requirement during time in cut averaged highest when machining 0.015-inch-thick flakes from cold hickory bolts 8 inches in diameter. For the 10-knife cutterhead rotating at 1,800 r/min, net average power demand was 120.0 horsepower (per 50 inches of bolt length) for the six hickory bolts so machined. One of the six bolts required an average of 142.3 horsepower (per 50 inches of bolt length). For the 54-inch commercial machine, addition of 22 idling horsepower would raise average demand to 164 horsepower for a 10-knife head (1,800 r/min) that is removing 0.015-inch flakes while machining a cold, dense hickory bolt from 8-inch to 4-inch diameter (bolt length 50 inches).

Thicker flakes were cut with only five knives mounted in the head, and therefore had less average net cutting power demand when machining cold hickory bolts 8 inches in diameter:

Flake thickness	Number of knives cutting	Average net cutterhead power per 50 inches of bolt length
Inch		*Horsepower*
0.015	10	120.0
.025	5	81.1
.035	5	83.2

As may be deduced from table 2 (specific cutting energy), loblolly pine required only about two-thirds the average net cutterhead power needed for hickory.

Average Net Cutterhead Horsepower Per 50 Inches of Bolt Length Per Knife

Horsepower per knife is a useful statistic in designing cutterheads. At 1,800 r/min the overall average was 9.94 net per knife per 50 inches of bolt length. (Doubling the cutterhead speed would double this value.) Highest average readings occurred when machining 8-inch hickory to 4-inch rounds at 72° F:

Flake thickness	Average cutterhead power per 50 inches of bolt length per knife
Inch	*Horsepower*
0.015	12.00
.025	16.23
.035	16.63

The highest individual value observed when cutting 0.015-inch cold hickory flakes was 14.2. This value is important because it is a determinant of motor size on the production machine. Thus a 10-knife, 1,800 r/min head making a 2-inch-deep cut in a 50-inch-long, cold hickory bolt would have a net average requirement of 142 horsepower when cutting 0.015-inch-thick flakes.

For the commercial machine, a cutterhead speed of 3,600 r/min would permit the use of fewer knives than one turning at 1,800, and a head with six knives cutting would allow more flexibility than one with 10 knives. For a six-knife head turning at 3,600 r/min the average horsepower needed would be 170, i.e., (14.2) (6) (3,600/1,800). To this value must be added idling horsepower. To cut flakes thicker than 0.015 inch, the number of knives could be reduced by removing every other knife, thereby keeping about the same workpiece rotational speed but reducing the average power requirement.

Average Net Cutterhead Horsepower Per 50 Inches of Bolt Length Per Knife Per Inch Depth of Cut

The foregoing paragraphs discussed the average horsepower required to cut an 8-inch bolt to a 4-inch cylinder, i.e., to take a cut 2 inches deep. The data permit analyses of cuts 1, 1.5, and 2 inches deep. Figure 17 shows that the relationship between cutting depth and horsepower is linear in this range. It will be noted, however, that the plots do not pass through the origin, but have a Y intercept (about 15 horsepower). That is, a doubling of depth of cut does not quite double the net average horsepower required.

For all 432 bolts, the average for the 1,800 r/min cutterhead was 6.75 net horsepower per 50 inches of bolt length per knife per inch depth of cut. Highest averages occurred with cold hickory:

Flake thickness	Average cutterhead power per 50 inches of bolt length per knife per inch depth of cut
Inch	*Horsepower*
0.015	6.89
.025	10.35
.035	9.94

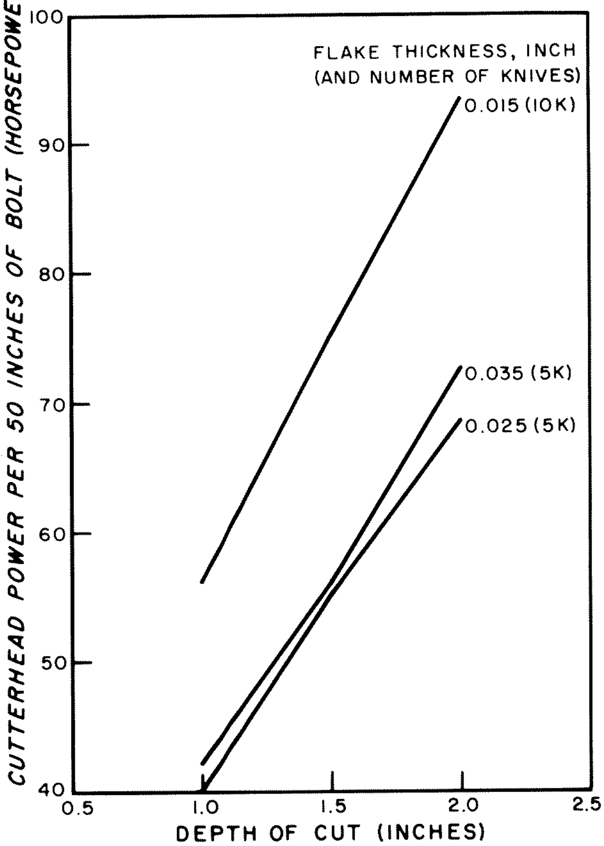

Figure 17.—*Relationship of depth of cut to average net cutterhead power required per 50 inches of bolt length. Data from all four species and both wood temperatures were pooled. The 0.015-inch-thick flakes were cut with 10 knives; a five-knife head was used to cut the thicker flakes. Data from 48 bolts were averaged to locate each of the nine points plotted.*

The highest average value observed when cutting 0.015-inch cold hickory flakes was 7.53. If this value is extended to cuts deeper than 1.5 inches it will likely be conservative—i.e., a head so designed will have excess power because the curves in figure 17 do not pass through the origin.

It can be assumed that the heaviest cut to be made on the production machine is manufacture of a 6-inch round from a bolt 12 inches in diameter and 50 inches long. Then a 10-knife head cutting 0.015 flakes from cold hickory will draw 226 net average horsepower at 1,800 r/min, i.e., (7.53) (10) (3-inch depth of cut). A six-knife head at 3,600 r/min would average 271 horsepower, i.e., (7.53) (6) (3) (3,600/1,800). Idling power must be added to these values.

It is hard to visualize an operator calling for such a deep cut, but he may be pressed to fill orders when he has only large wood on hand.

Maximum Net Cutterhead Horsepower Per 50 Inches of Bolt Length

Motor size in the lathe headrig is determined not only by average power drawn during the few seconds the head is in the cut, but also by the maximum power drawn during each cut. These maximums, occurring about six times per minute, must not cause motor overheating nor exert sufficient torque to slow the motor from synchronous speed, i.e., "pull out."

The power curves displayed no sharp peaks when 6-, 7-, and 8-inch bolts were cut to 4-inch cylinders, but maximum values were easily noted where wood density patterns were eccentric. Power maximums were greatest when 0.015-inch flakes were cut from cold hickory bolts 8 inches in diameter. Then maximum power demand by a 10-knife head at 1,800 r/min was 218.0 horsepower per 50 inches of bolt length for the six hickory bolts so machined. One of the six bolts peaked at 232.9 net horsepower.

For all 432 bolts the mean value of maximum net horsepower per 50 inches of bolt length was 116.5. Bolts at 160° F needed 5.5 percent less (113.2) than those cut at 72° F (119.8).

The trend evident in figure 17 also appears in the linear relationship of maximum power to depth of cut, as follows:

Bolt diameter	Depth of cut	Maximum net cutterhead power per 50 inches of bolt length
Inches	*Inches*	*Horsepower*
6	1.0	83.2
7	1.5	117.0
8	2.0	149.3

Loblolly pine drew only 70 percent of the maximum required by hickory, and the 10-knife head cutting 0.015-inch-thick flakes drew maximums substantially greater than the five-knife head cutting 0.025- and 0.035-inch flakes:

Species	0.015	0.025	0.035	Average
	Maximum net horsepower per 50 inches of bolt length			
Loblolly pine	121.3	79.1	94.0	98.1
Sweetgum	120.6	88.9	106.1	105.2
Southern red oak	150.5	100.8	119.0	123.4
Hickory	167.7	118.9	131.2	139.2
Average	140.0	96.9	112.6	

(Flake thickness, inch: 0.015, 0.025, 0.035)

Maximum Net Cutterhead Horsepower Per 50 Inches of Bolt Length Per Knife

Overall mean maximum horsepower per knife per 50 inches of bolt length was 18.6. The largest maximums occurred when machining cold 8-inch hickory to 4-inch rounds:

Flake thickness	Maximum net cutterhead power per 50 inches of bolt length per knife
Inch	*Horsepower*
0.015	21.80
.025	28.30
.035	32.94

The highest individual net maximum observe when cutting 0.015-inch cold hickory flakes (2 inch depth of cut) was 23.3 per 50 inches of bo length per knife.

Thus a 10-knife, 1,800-r/min head cutting inches deep in a 50-inch-long bolt would draw net maximum of 233 horsepower when makin 0.015-inch flakes from cold, dense hickory. Wit six knives at 3,600 r/min, the maximum woul likely be 280 horsepower, i.e., (23.3) (6) (3,600 1,800)—or about 302 with idling horsepowe added.

Maximum Net Cutterhead Horsepower Per 50 Inches of Bolt Length Per Knife Per Inch Depth of Cut

Since the relationship between maximum ne horsepower and depth of cut is linear, it is usefu to express maximum net horsepower in term of depth of cut. For all 432 bolts, the average fo the 1,800 r/min cutterhead was 12.56 per 5 inches of bolt length per knife per inch depth o cut. Wood soaked in hot (160° F) water ha maximums 5.3 percent less than wood machine at 72° F (12.22 vs. 12.91 horsepower).

The maximums were positively correlate with specific gravity (fig. 18) and with flak thickness (table 3 and fig. 19).

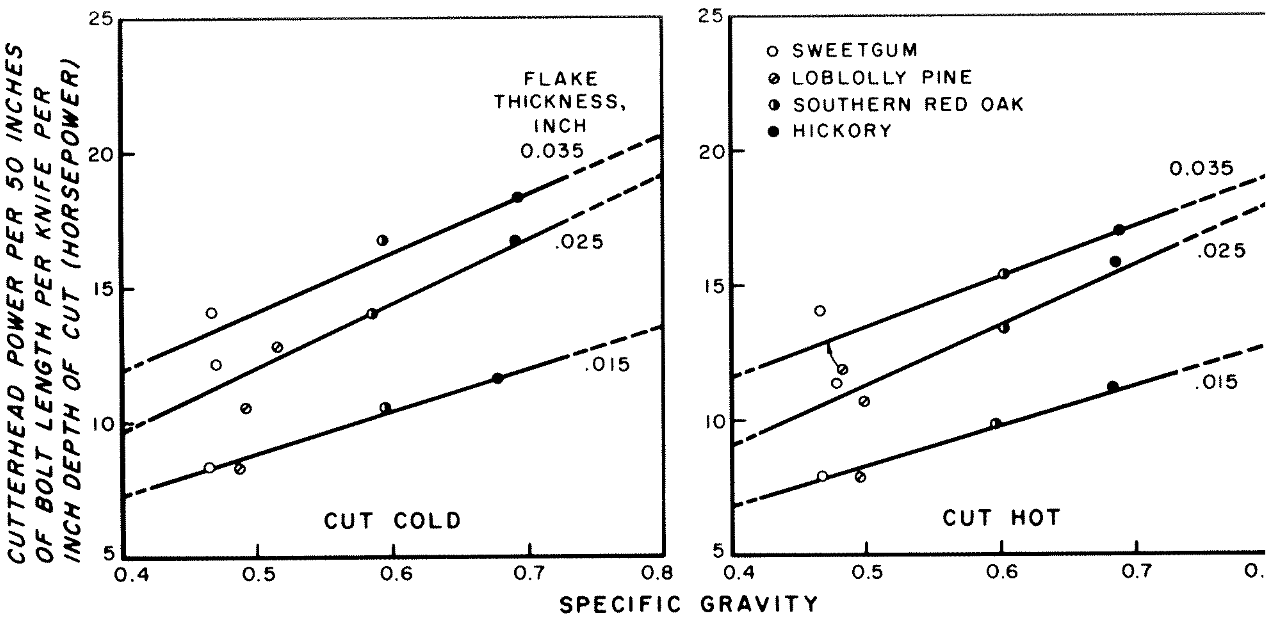

Figure 18.—*Regression of maximum observed (per cutting cycle) net cutting horsepower per 50 inches of bolt length per knife per inch depth of cut, on wood specific gravity (basis of ovendry weight and green volume). Plotted points are 18-bolt averages for the species named and are based on cuts 1.0, 1.5, and 2.0 inches deep. Cutterhead speed was 1,800 r/min.*

Table 3.—*Maximum net cutterhead horsepower per 50 inches of bolt length per knife per inch depth of cut*

Temperature and species	Flake thickness, inch			
	0.015	0.025	0.035	Average
	Horsepower			
Cut cold				
Loblolly pine	8.40	10.63	12.94	10.66
Sweetgum	8.40	12.19	14.21	11.60
Southern red oak	10.64	14.04	16.86	13.85
Hickory	11.56	16.70	18.36	15.54
Average	9.75	13.39	15.59	
Cut hot				
Loblolly pine	7.92	10.52	11.85	10.10
Sweetgum	7.93	11.47	14.07	11.16
Southern red oak	9.84	13.36	15.43	12.88
Hickory	11.20	15.91	17.08	14.73
Average	9.22	12.81	14.61	

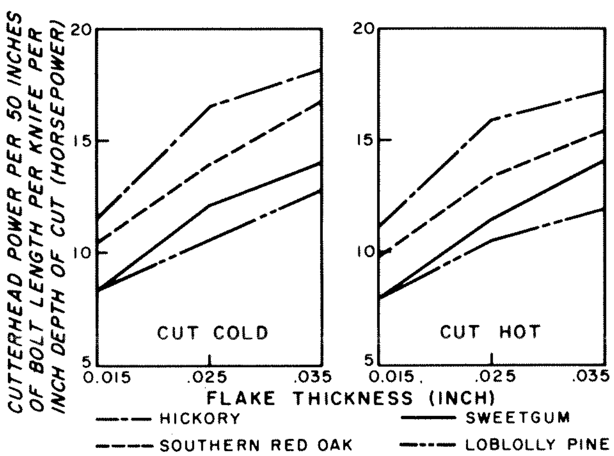

Figure 19.—*Maximum net cutterhead horsepower observed in each machining cycle per knife per 50 inches of bolt length per inch depth of cut, related to average flake thickness, species, and wood temperature. Data from 18 bolts were averaged to locate each of the 24 points plotted. Cutterhead speed was 1,800 r/min.*

The regression equations graphed in figure 18, with squared correlation coefficients and square roots of error mean squares (values of S_e are in horsepower minutes per cubic foot), are as follows:

Wood cut at 72° F

0.015-inch flakes ($R^2 = 0.61$; $S_e = 1.16$)

$$\hat{Y} = 1.0427 + 15.6451\ X$$

0.025-inch flakes ($R^2 = 0.52$; $S_e = 2.15$)

$$\hat{Y} = 0.1551 + 23.6785\ X$$

0.035-inch flakes ($R^2 = 0.46$; $S_e = 2.22$)

$$\hat{Y} = 3.2659 + 21.7839\ X$$

Wood cut at 160° F

0.015-inch flakes ($R^2 = 0.51$; $S_e = 1.33$)

$$\hat{Y} = 0.9257 + 14.8163\ X$$

0.025-inch flakes ($R^2 = 0.54$; $S_e = 1.87$)

$$\hat{Y} = 0.1725 + 22.2934\ X$$

0.035-inch flakes ($R^2 = 0.58$; $S_e = 1.57$)

$$\hat{Y} = 4.2001 + 18.5873\ X$$

From figure 18 it is evident that the maximum power demand occurs when the most dense wood is machined cold. If 0.8 specific gravity is the upper limit for mixed eastern hardwoods, then (by the first equation listed above) the maximum net cutterhead power for 0.015-inch-thick flakes will be about 13.6 horsepower per 50 inches of bolt length per knife per inch depth of cut. Under these conditions, a 10-knife head rotating at 1,800 r/min would draw 272 maximum net horsepower in machining an 8-inch square from a cold bolt 12 inches in diameter and 50 inches long. Net maximum for a six-knife head rotating at 3,600 r/min would be 326.

Should the depth of cut be increased from the 2 inches assumed above to 3 inches, maximum net horsepower would be 408 for the 10-knife head (1,800 r/min) and 490 for the six-knife head (3,600 r/min).

These maximums perhaps overstate the requirement somewhat because the relationship between depth of cut and horsepower—while linear—is not quite directly proportional; i.e., doubling the depth of cut in oak and hickory does not quite double the maximum net horsepower required. In the following tabulation, all factors are pooled except depth of cut and species:

Species	Depth of cut, inches			
	1.0	1.5	2.0	Average
	Maximum net horsepower per 50 inches of bolt length per knife per inch depth of cut			
Loblolly pine	10.52	9.97	10.64	10.38
Sweetgum	11.50	11.42	11.21	11.38
Southern red oak	14.48	13.36	12.25	13.36
Hickory	16.41	15.25	13.74	15.13
Average	13.23	12.50	11.96	

Because the 6-inch hickory bolts were most dense, the highest net maximum occurred with these bolts when cut cold:

Flake thickness	Maximum net cutterhead power per 50 inches of bolt length per knife per inch depth of cut
	Horsepower
0.015	12.61
.025	19.57
.035	19.35

Of the six 6-inch, cold-cut hickory bolts machined to yield 0.015-inch flakes, one had 13.96 maximum requirement. This is not much different from the value of 13.6 previously postulated from figure 18. These are the values which will size the motor, because flakes thicker than 0.015 inch can be cut by removing every other knife from the cutterhead, thus reducing peak power demands.

CONCLUSIONS

The purpose of this experiment was to determine the minimum cutterhead motor that will permit the commercial shaping-lathe headrig to machine six bolts per minute. In reaching conclusions, some design parameters of the cutterhead and feedworks are assumed, as follows:

Cutterhead
- Direction of workpiece rotation ... upmilling
- Cutterhead speed ... 3,600 r/min
- Cutterhead length ... 54 inches
- Diameter of cutting circle ... 12 inches
- Number of knives cutting when machining flakes 0.015-inch thick ... 6
- Alternate numbers of knives (by removal) ... 3
- Cutterhead idling power ... 22 horsepower

Workpiece
- Maximum workpiece diameter ... 12 inches
- Maximum density of wood to be machined (basis of ovendry weight and green volume) ... 0.75
- Condition of workpiece ... green at 72° F
- Maximum length of workpiece ... 53 inches

Feedworks and Sets
- Maximum depth of cut (at knots, crooks, eccentricities) on which to base estimate of momentary maximum horsepower demand ... 3 inche
- Maximum removal of cross section on which to base average net cutterhead power demand ... 12-inch round to 8-inch squai
- Speed ratios on variable-speed gearmotor driving the workpiece ... 3:

Average Horsepower During Cutting Cycle

To convert specific cutting energy data t average horsepower demand, the time in cu must be known. In the discussion that follows, : will be assumed that 0.015-inch flakes are bein cut with a six-knife head turning at 3,600 r/mi The workpiece—not rotating—approaches th cutterhead at 5.4 inches per second until the fo lower strikes the cam. Thereupon, the work piece rotates through 360 at 10.31 r/min.

Time in cut is therefore comprised of tw components:

- Plunge time in cut (e.g., 2 inches when machining an 8-inch square from a 12-inch round)
- Time to rotate 360 degrees

Plunge time is 2/5.4 seconds or 0.37 second, an time to rotate 360 degrees is 5.82 seconds. There fore total time in cut is $0.37 + 5.82 = 6.19$ sec onds or 0.103 minute.

Volume of wood removed from each 53-inch long, 12-inch-diameter bolt machined to an 8- b 8-inch-square cant amounts to 1.506 cubic fee i.e., $(0.5^2 \pi - .67^2)$ (53/12).

At a wood specific gravity of 0.75, specif cutting energy for 0.015-inch flakes is 16.7 horsepower minutes per cubic foot of cold woo removed (fig. 15, left). Average net horsepowe demand to reduce a 12-inch bolt to an 8-inc square is therefore 245 horsepower, i.e., (16.77 (1.506)/0.103. To this must be added the 2 horsepower required to turn the cutterhead whe idling. Total average cutterhead horsepower ex pended over the 6.19-second machining cyc will therefore be 267.

If the operator reduced the number of knive cutting from six to three, so as to increase ave age flake thickness from 0.015 to 0.030 inch, ne average cutterhead power would be reduce about 25 percent (fig. 16, left, hickory). The total then would be 206, i.e., (245) (.75) + 22.

Maximum Horsepower During Cutting Cycle

Maximum power is a function of the horsepower per knife per inch depth of cut adjusted for bolt length and cutterhead speed. When machining 0.015-inch flakes from cold wood of 0.75 specific gravity, maximum net cutterhead horsepower per 50 inches of bolt length, per knife, per inch depth of cut is 12.78 at 1,800 r/min or 25.56 at 3,600 r/min.

For a 3-inch depth of cut on a bolt 53 inches long, maximum cutting power will therefore be 488 horsepower, e.g., (2) (12.78) (6) (3) (53)/50—or 510 when idling power is included.

The operator of the production machine is almost certain to make 3-inch-deep cuts occasionally—because of bolt eccentricity if for no other reason. Sometimes a 3-inch cut will extend the full bolt length of 53 inches.

Should the operator reduce the number of knives cutting from six to three and increase flake thickness to 0.030, maximum net cutterhead horsepower would be about 334, or 356 with idling power added.

Workpiece Rotational Speed

Flakes for structural flakeboard may be required in thicknesses ranging from 0.015 to 0.030 inch. In the commercial headrig contemplated, cutterhead rotational speed is fixed at 3,600 r/min. Flake thickness is therefore controlled by varying either the workpiece rotational speed or the number of knives cutting.

In the following discussion it is assumed that a variable-speed gearmotor can give workpiece speeds with maximum three times the minimum. It has been noted that a bolt 12 inches in diameter being machined to an 8-inch square must turn at 10.31 r/min to yield flakes averaging 0.015 inch thick when cut with a six-knife cutterhead turning at 3,600 r/min. The tabulation below was constructed on the assumption that the operator would change workpiece rotational speed in the range from 9 to 27 r/min to correspond with average diameter (i.e., the diameter midway between bolt diameter and machined diameter). Four flake thicknesses would be available by operating with six or three knives cutting:

Number of knives cutting (and average flake thickness, inch)	Workpiece diameter at which flake thickness is measured, inches		
	5	7.5	10
	Workpiece r/min		
6 knives cutting			
0.015	20.62	15.47	10.31
.020	27.49	20.63	13.75
3 knives cutting			
.25	17.18	12.89	8.59
.30	20.62	15.47	10.31

Power Required to Rotate Workpiece, and Workpiece Deflection in Torsion

In order for a 12-inch-diameter cutterhead rotating at 3,600 r/min to have average demand of 245 horsepower while cutting, it must exert a force of 715 pounds tangential to its cutting circle.

If 0.015-inch flakes are to be cut at an average diameter of 10 inches, with workpiece rotation speed of 10.31 r/min, only 0.58 hp is required to rotate the workpiece while an 8-inch square is cut from a 12-inch round, i.e., (π) (10/12) (10.31) (715)/33,000.

Torque exerted by the driving chuck must not unduly twist the workpiece, or machined squares will tend to assume a propeller shape. The following calculations are intended to show that the maximum torsional deflections anticipated will not be of substantial practical importance.

Assume that the 53-inch-long workpiece is driven from one end and that the 715-pound force noted in the previous paragraph is applied as a concentrated load to the idle chuck end in a manner to deliver (715) (5 inches) or 3,575 inch-pounds of torque. Further assume that the machined workpiece is an 8-inch cylinder. Both assumptions are conservative, i.e., the workpiece is actually 8 inches square and the load of 715 pounds is uniformly distributed along the bolt.

Under these assumptions, the workpiece would deflect (at the idle-chuck end from the driven-chuck end) through an angle of 0.270 degree, as follows:

Angle of deflection $\Theta = \frac{TL}{JG}$; where Θ is in radians, T is torque (inch pounds), L is bolt length (inches), J is polar moment of inertia ($\frac{\pi D^4}{32}$, inches^4), and G is modulus of rigidity (assumed to be 100,000 lb/in^2)

Therefore:

$$\Theta = \frac{(3{,}575)\ (53)}{(402.1)\ (100{,}000)} = 0.00471 \text{ radians}$$
$$= 0.270 \text{ degree}$$

This would deflect a point on the periphery of the workpiece 0.019 inch, e.g. $(\frac{0.270}{360})$ (8π), from the unstressed position.

If this same 715-pound force was applied at 2.5-inch radius to twist a 4-inch post, the torque would be halved and the polar moment of inertia decreased 16 times; therefore the post would twist through an angle Θ of (0.270) (16)/2 = 2.16 degrees, and a point on the periphery at one end would deflect 0.075 inch, e.g., (2.16) (π) (4)/360.

It is likely that these torsional deflections are within acceptable limits. Should they prove to be excessive, however, application of power to both workpiece chucks—rather than only one—would diminish them by a factor of 4.

Lateral Deflection of the Workpiece

Assuming a tangentially and uniformly applied bending load—due to parallel cutting forces—of 715 pounds over the 53-inch length of an 8-inch machined cylinder (when cutting a dense wood such as *Quercus bicolor* Willd.), the cylinder would deflect 0.0043 inch, e.g., $5wL^4/384EI$. This assumes an E of 1,590,000 lb/in^2.

From tables 19-8 and 19-10 of Agriculture Handbook 420 (Koch 1972), it is seen that the ratio of knife normal force to parallel cutting force is $\frac{-0.4}{1.7}$ when 0.015-inch-thick chips are cut in the 0-90 direction from saturated wood of high density (loblolly latewood) with a knife having a 45-degree rake angle. Therefore, the workpiece will tend to be drawn into the cutterhead by uniformly distributed force of —168 pound i.e., (—0.4) (715)/1.7. Resulting deflection (t ward the cutterhead) at midpoint of an 8-inc cylinder will be 0.0010 inch.

These same loads applied to a 4-inch roun post will cause deflections 16 times larger, i.e 0.069 inch in a downward direction, and 0.01 inch toward the cutterhead.

It is probable that these workpiece bending d flections are within acceptable limits for man facture of pallet parts and other industrial lun ber products.

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